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Effect of Short Circuits on an Alternator

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EFFECT OF SHORT CIRCUITS ON AN ALTERNATOR

BY

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NOTATION.

Capital letters denote maximum values; small letters denote effective values; small letters with subscripts denote instantaneous values.

E = voltage generated in armature under short circuit.

I, i = current.

x = reactance of armature.

r = resistance of armature.

x_0 = reactance of field expressed as per cent of ármature reactance.

r_0 = resistance of field expressed as per cent of armature resistance.

Z = impedance.

Z_s = synchronous impedance.

θ = time in radians counted from time of closing switch.

θ_1 = time in electrical degrees counted from time of zero emf. before circuit is closed.

$$\frac{R}{X} = \frac{r}{x} - \frac{r_0}{x_0}$$

EFFECT OF SHORT CIRCUITS ON AN ALTERNATOR.

I. INTRODUCTION.

The purpose of this thesis is to show how a short circuit on an alternator effects the current and power on the machine, and to bring out the reasons for such action.

Considerable time and effort has been put forth by designing engineers to predetermine the characteristics of a generator under short circuit for all conditions of load.

The operating engineer, on the other hand, is brought directly in contact with the machines on short circuit and it is to protect him as well as for economic reasons, that the designing engineer has to construct machines ranging from ten to twenty thousand kilowatts, which will withstand the dead short.

This thesis is written from an entirely different point of view, with the one object being to bring out clearly the action of the current and power produced in the alternator, when, for any reason, it becomes short circuited, and the effect of these two when the short occurs on various positions of the voltage wave.

In preparing this thesis, reference was made to Steinmetz's "Theoretical Elements of Electrical Engineering", "Theory and Calculation of alternating Current Phenomena", "Standard Handbook", and various magazines and journals.

II. THEORY.

We know that when a change of terminal voltage of an alternating current generator, resulting from a change of load at constant field excitation, is produced, it is due to the combined effect of armature reaction and armature self induction. The counter m.m.f. of armature current, or armature reaction, combines with the impressed m.m.f., or field excitation which produces a resultant magnetic field in the field poles, and generates an e.m.f. in the armature called the "virtual generated e.m.f.", since it is only a fictitious value and does not really exist. The counter e.m.f. of self induction of the armature current, combines with the virtual generated e.m.f. to produce the actual e.m.f. generated in the armature, the latter corresponding to the magnetic flux in the armature core. This e.m.f. less the resistance drop in the armature gives the terminal voltage.

Usually the effect of armature reaction and of self induction are similar in character, and are thus contracted into one constant, the self induction being represented by an increase of armature reaction. In other words an effective armature reaction is used which combines the effect of the true armature reaction and armature self induction. In a similar manner the armature reaction is sometimes represented by an effective self induction, where the e.m.f., which would be generated by the magnetic flux which armature reaction would produce, is considered rather than the m.m.f. of armature reaction. This is known as "synchronous reactance".

Although armature reaction and self induction are similar

in effect, under vauious conditions they differ in their actions. The e.m.f. of self induction is almost instantaneous, that is, it appears and disappears with the current which produced it. The effect of armature reaction, however, requires more time. The change of the magnetic field resulting from the combination of the counter m.m.f. of armature reaction with the impressed m.m.f. of field excitation occurs gradually, since the magnetic field flux interlinks with the field winding, and any change in the field generates an e.m.f. in the field circuit which temporarily increases or decreases the field current and so retards the change in the field flux. A sudden change of load, if increasing, will increase the counter e.m.f. of self induction and counter m.m.f. of armature reaction. With the armature reaction demagnetizing the field, the field flux begins to decrease, and thus generates an e.m.f. in the field exciting circuit which increases the field current and checks the decrease of field flux so that the latter adjusts itself gradually to the change in the circuit, the rate of adjustment depending upon the constants of the circuit.

The extreme case is when an alternator is short circuited. At the first moment the current is limited only by self induction, and the magnetic field still has full strength; the field exciting current is increased by the e.m.f. generated in the field circuit by the armature reaction. Gradually the field exciting current and the field magnetism die down to the values corresponding to short circuit conditions. Thus the momentary short circuit current of an alternator is far greater than the permanent short circuit current. When short circuited at full load it is usually from

three to fifteen times as great as full load current depending on the position of the current wave that the short circuit occurs, as shown in the following diagrams.

It is $I_o = \frac{E_o}{Z_s}$

where E_o = nominal generated d.m.f.

Z_s = synchronous impedance, representing the combined effect of armature reaction and armature self induction.

In the first moment, however, we have $I_1 = \frac{E_o}{Z}$ where Z = self inductive impedance of the alternator. That is, in the first moment after short-circuiting, the armature current is limited only by the armature self inductance, and not by armature reaction, and it is usually several cycles before the armature reaction becomes wholly effective.

As explained above the armature current rises to a value giben by the e.m.f. generated by the full field flux, while the field current rises to many times its normal value, gradually the field flux decreases, and with it, decrease the field current and armature current, at a rate depending on the resistance and inductance of the field exciting circuit. The decrease in value of field flux will be the more rapid the higher the resistance of the field circuit; the slower.the higher the inductance.

The value of the current upon short circuiting an alternator depends also on the position of the current wave that the circuit is closed. Thus in the circuit, Fig. I, theoretically

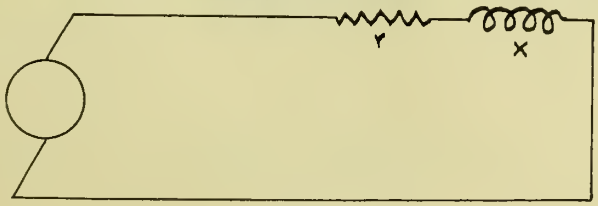


Fig. I.

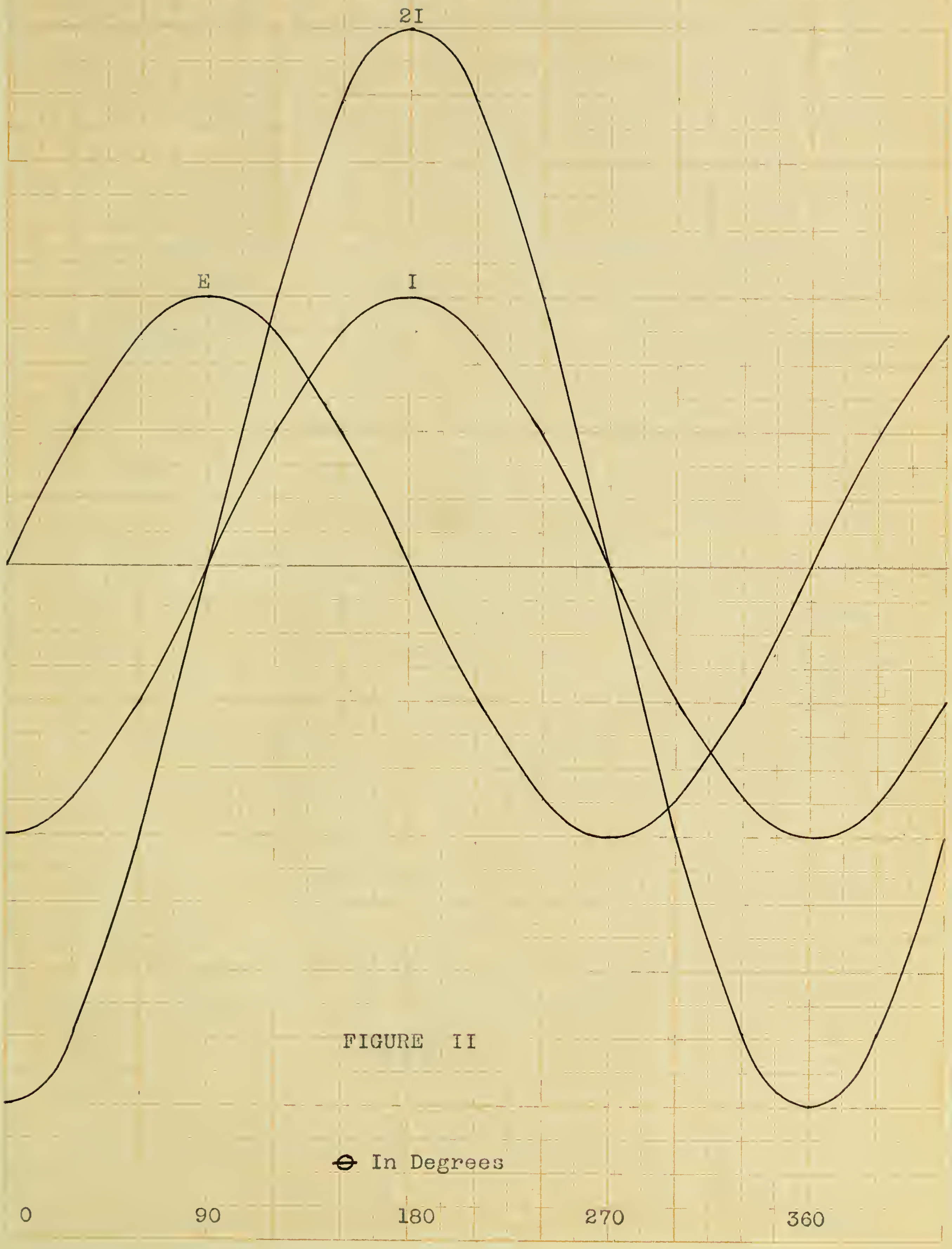


FIGURE II

we should have a flux produced which should be maximum at the point where the voltage is zero. If the circuit is closed at the point where E equals zero, the current must increase to 2 I, or the flux to 2Φ in a positive direction between the time interval π and 2π in order to produce counter e.m.f. sufficient to produce normal current, and the current will continue to pulsate as long as the circuit remains closed and constant potential is impressed. Were the circuit closed at some other point between zero and maximum values of e.m.f., say 120°, I would have a positive value of $I_0 \sin 120^\circ = .866\ I_0$. Since the maximum change of I must be 2 I to correspond to 2Φ, the maximum flux must be $(2 - .866)I$ or $1.134\ \Phi$ or $1.134\ I_0$. In other words, if the circuit were closed at the instant of zero value of normal current, the normal current will instantly be produced, but if it were closed when normal current had its maximum value, that is zero value of induced e.m.f., a momentary rush of current ensues, followed by a transition period which continues until the current becomes normal to the new conditions imposed. In theory this period is indefinite, but in reality it is a fraction of a second, depending upon values of i and x.

The value of the short circuit current may be calculated as follows:--

The fundamental equation of an alternating current circuit containing resistance and inductance only is

$$e = i\,r + x\frac{di}{d\theta}$$

where e = generated e.m.f.

Assuming the voltage wave to be a sine wave we have

$$e = E \sin\theta \qquad \text{or} \qquad e = E\,\varepsilon^{-\frac{r_0}{x_\theta}(\theta - \theta_1)} \sin\theta$$

where θ_1 is the time of closing the short circuiting switch.

E = maximum value of e.m.f.

r_0 = resistance of field.

x_0 = reactance of field.

Equating these two values of e we have

$$E\,\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\sin\theta = ir + x\frac{di}{d\theta}$$

or

$$\frac{di}{d\theta} + \frac{ir}{x} = \frac{E}{x}\,\epsilon^{-\frac{r_0(\theta-\theta_1)}{x_0}}\sin\theta$$

Integrating--

$$i = \epsilon^{-\frac{r}{x}\theta}\left[\int \epsilon^{\frac{r}{x}\theta}\,\frac{E}{x}\,\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\sin\theta\, d\theta + c\right]$$

$$i = \epsilon^{-\frac{r}{x}\theta}\,\frac{E}{x}\left[\int \epsilon^{\frac{r}{x}\theta}\,\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\sin\theta\, d\theta + c\right]$$

Grouping the exponents of ϵ

$$\epsilon^{\frac{r}{x}\theta - \frac{r_0}{x_0}(\theta-\theta_1)} = \epsilon^{\left(\frac{r}{x} - \frac{r_0}{x_0}\right)\theta + \frac{r_0}{x_0}\theta_1}$$

Call $\frac{r}{x} - \frac{r_0}{x_0} = \frac{R}{X}$

Then

$$i = \frac{E}{x}\,\epsilon^{-\frac{r}{x}\theta + \frac{r_0}{x_0}\theta_1}\int \epsilon^{\frac{R}{X}}\sin\theta\, d\theta + c\,\epsilon^{-\frac{r}{x}\theta}$$

Integrating $\int \epsilon^{\frac{R}{X}\theta}\sin\theta\, d\theta$ by the

$\int u\, dv = uv - \int v\, du$ method

$$\int \epsilon^{\frac{R}{X}\theta}\sin\theta\, d\theta = -\epsilon^{\frac{R}{X}\theta}\cos\theta + \frac{R}{X}\int\cos\theta\,\epsilon^{\frac{R}{X}\theta}\, d\theta$$

$$= \epsilon^{\frac{R}{X}\theta}\cos\theta + \frac{R}{X}\sin\theta\,\epsilon^{\frac{R}{X}\theta} - \frac{R^2}{X^2}\int\sin\theta\,\epsilon^{\frac{R}{X}\theta}\, d\theta$$

but

$$\frac{R^2 + X^2}{X^2}\int\sin\theta\,\epsilon^{\frac{R}{X}\theta}\, d\theta = -\epsilon^{\frac{R}{X}\theta}\cos\theta + \frac{R}{X}\sin\theta\,\epsilon^{\frac{R}{X}\theta}$$

$$R^2 + X^2 = Z^2$$

and $\int \sin\theta\, \epsilon^{\frac{R}{X}\theta} d\theta = \frac{X^2}{Z^2}\left[-\epsilon^{\frac{R}{X}\theta}\cos\theta + \frac{R}{X}\sin\theta\,\epsilon^{\frac{R}{X}\theta}\right]$

$$\therefore\ i = \frac{E}{x}\epsilon^{-\frac{r}{x}\theta + \frac{r_0}{x_0}\theta_1}\epsilon^{\frac{r}{x}\theta - \frac{r_0}{x_0}\theta}\left[\frac{X^2}{Z^2}\left(-\cos\theta + \frac{R}{X}\sin\theta\right)\right] + c\,\epsilon^{-\frac{r}{x}\theta}$$

$$= \frac{E}{x}\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\ \frac{X}{Z}\left[-\frac{X}{Z}\cos\theta + \frac{R}{Z}\sin\theta\right] + c\,\epsilon^{-\frac{r}{x}\theta}$$

$$R = Z\cos\beta$$

$$X = Z\sin\beta$$

$$\therefore\ i = \frac{E}{x}\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\frac{X}{Z}\left[-\frac{Z\sin\beta}{Z}\cos\theta + \frac{Z\cos\beta}{Z}\sin\theta\right] + c\,\epsilon^{-\frac{r}{x}\theta}$$

$$= \frac{X\,E}{Z\,X}\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\left(\sin[\theta-\beta]\right) + c\,\epsilon^{-\frac{r}{x}\theta}$$

when $\theta = \theta_1$

then $e = -\frac{X\,E}{Z\,X}\sin(\theta_1-\beta)\,\epsilon^{\frac{r}{x}\theta_1}$

and $i = \frac{E\,X}{X\,Z}\left[\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\sin(\theta-\beta) - \sin(\theta_1-\beta)\,\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\right]$

Thus the value of current is

$$i = \frac{E\,X}{X\,Z}\left[\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\sin(\theta-\beta) - \sin(\theta_1-\beta)\,\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\right]$$

which is a pulsating value as seen, depending on the sine values of $(\theta-\beta)$ and $(\theta_1-\beta)$. This equation only holds until the current has decreased to a value of normal current where

$i = \frac{E}{Z_s}\sin(\theta-\beta)$, which we call the "permanent value" of current.

This value of current is for the short circuit of a single phase only. The short circuiting of three phases at once does not effect the current in the separate phases, but the short

circuit current in the separate phases reaches their maximum values 120 degrees apart.

To find the power on short circuit, we know that power equals e i. From the first part of this development we have

$e = E \epsilon^{-\frac{r_o}{x_o}(\theta - \theta_1)} \sin \theta$ which is approximately true for the first few cycles.

$$\therefore \quad e\,i = E \epsilon^{-\frac{r_o}{x_o}(\theta - \theta_1)} \sin \theta \left[\frac{E}{x}\left(\epsilon^{-\frac{r}{x}(\theta - \theta_1)} \cos \theta_1 - \epsilon^{-\frac{r_o}{x_o}(\theta - \theta_1)} \cos \theta\right)\right]$$

which is true for the first few cycles. The power shown above is only for short circuit on one phase. If the three phases are short circuited at once, the resulting power is independent of angle at which short circuit occurs.

Figure III gives the value of the function $y = \epsilon^{-x}$ for values of x from 0 to 3; Figure IV for values of x from 3 to 10. The curves are plotted from the following data:-

x	ε^{-x}	x	ε^{-x}
.00	1.00	.80	.449
.02	.98	.85	.427
.04	.96	.90	.407
.06	.942	.95	.387
.08	.923	1.0	.368
.10	.905	1.1	.333
.12	.887	1.2	.301
.14	.870	1.3	.273
.16	.852	1.4	.247
.18	.835	1.5	.202
.20	.819	1.8	.165
.25	.78	2.	.135
.30	.741	2.5	.084
.35	.705	3.	.05
.40	.67	4.	.018
.45	.638	5.	.0067
.50	.607	6.	.0025
.55	.577	7.	.0009
.60	.549	8.	.00034
.65	.522	9.	.00012
.70	.497	10.	.00004
.75	.472		

FIGURE III

$Y = \varepsilon^{-x}$

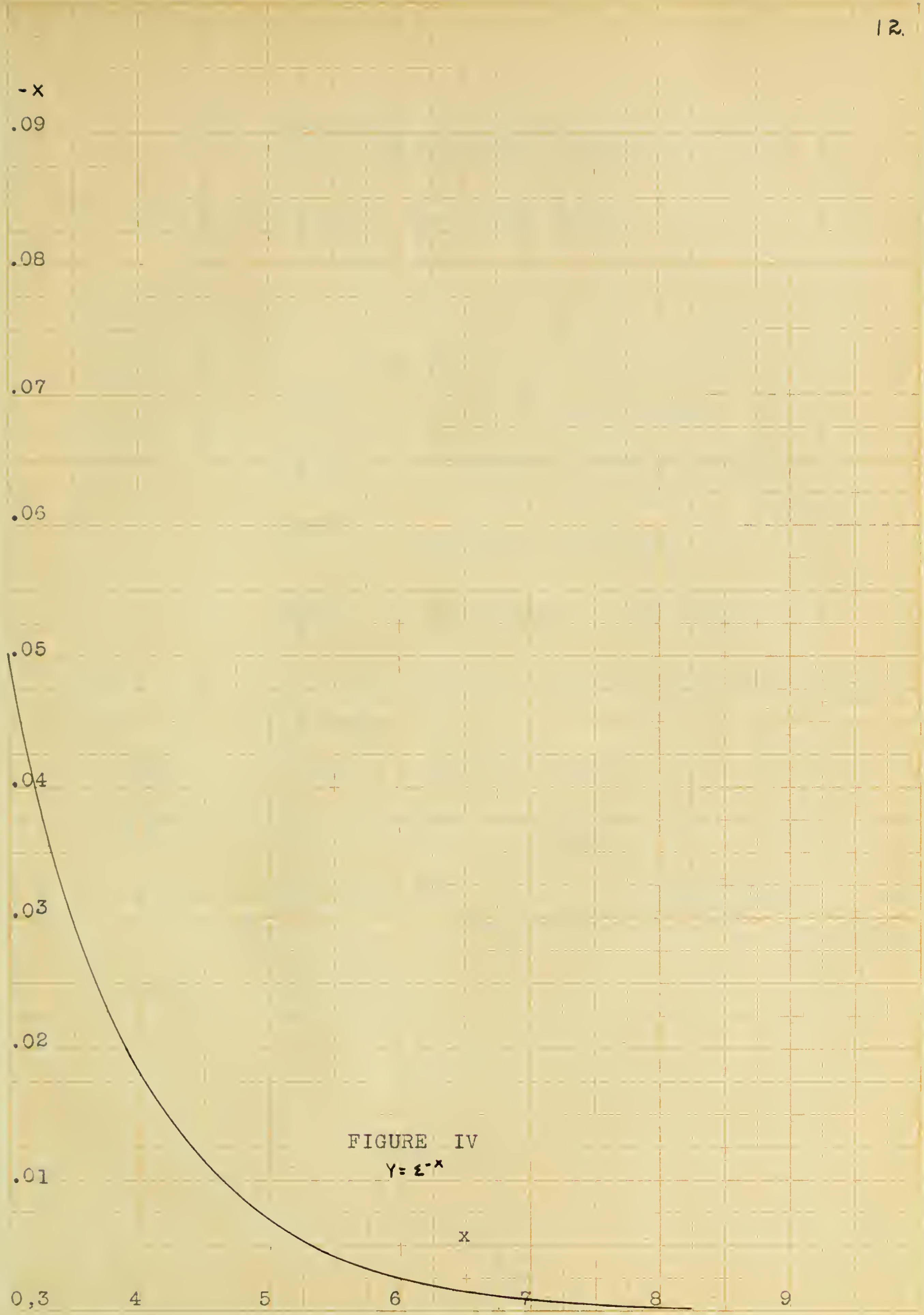


FIGURE IV

$Y = \varepsilon^{-x}$

III. INSTANTANEOUS VALUE OF CURRENT AND POWER DURING SHORT CIRCUIT.

A T B 4 - 12000 - 750 - 9000 Volts.

Y connected.

$r = .04$

$x = .4$

$r_0 = .1$

$x_0 = 3.$

$$\theta_1 = 120^\circ$$

$$\frac{9000}{\sqrt{3}} = 5200 \text{ Volts per phase.}$$

$$\frac{5200}{.707} = 7350 \text{ Volts} = \text{Maximum Value.}$$

$$\frac{12000}{3} = 4000 \text{ Kw. per phase.}$$

$$\frac{4000}{5200} = 770 \text{ Amperes} = I \text{ per phase.}$$

Assuming short circuit current to be twice the full load current we have $I_p = 1540$ amperes.

$$\frac{1540}{.707} = 2180 \text{ amperes} = \text{Maximum Value.}$$

$$i = \frac{E}{x}\left[\epsilon^{\frac{r}{x}(\theta - \theta_1)} \cos \theta_1 - \epsilon^{-\frac{r_0}{x_0}(\theta - \theta_1)} \cos \theta\right]$$

$$= \frac{12700}{3 \times .4}\left[\epsilon^{\frac{.04}{.4}\left(\frac{120 - 120}{57.4}\right)} \cos 120^\circ - \epsilon^{\frac{.1}{5}\left(\frac{120 - 120}{57.4}\right)} \cos 120^\circ\right]$$

$$= 18390 \left[0 - 0 \right]$$

CURRENT FOR θ_1 = ZERO

Cycle	1		2		3		4	
$\frac{E}{x}$	18390		18390		18390		18390	
θ	180	360	540	720	900	1080	1260	1440
θ_1	0	0	0	0	0	0	0	0
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	1	1	1	1	1	1	1	1
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.75	.55	.40	.29	.215	.16	.11	.08
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.94	.88	.825	.79	.74	.7	.66	.625
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	.75	.55	.40	.29	.215	.16	.11	.08
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.94	$\mp$.88	$\pm$.825	$\mp$.79	$\pm$.74	$\mp$.70	$\pm$.66	$\mp$.625
Difference	+1.69	-.33	+1.225	-.50	+.955	-.54	+.77	-.545
Diff.	+31000	-6050	+22500	-9200	+17550	-9940	+14150	-10000
$-\frac{r}{x}(\theta-\theta_1)$ radians	.314	.628	.942	1.756	1.580	1.88	2.20	2.51
$-\frac{r_0}{x_0}(\theta-\theta_1)$ "	.062	.125	.188	.251	.316	.376	.44	.502

CURRENT FOR θ_1 = ZERO

Cycle	5		6		7		8	
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	1620	1800	1980	2160	2340	2520	2700	2880
θ_1	0	0	0	0	0	0	0	0
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	1	1	1	1	1	1	1	1
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.057	.05	.035	.027	.027	.02	.016	.014
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.535	.55	.515	.49	.46	.426	.40	.375
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$ Cos θ_1	.057	.05	.035	.027	.025	.02	.016	.014
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$ Cos θ	$\pm$.585	$\mp$.55	$\pm$.515	$\mp$.49	$\pm$.46	$\mp$.426	$\pm$.40	$\mp$.375
Difference	+.642	-.50	+.548	-.463	+.485	-.406	+.416	-.361
Diff.	+11800	-9195	+10100	-8520	+8910	-7460	+7650	-6640
$-\frac{r}{x}(\theta-\theta_1)$ rad.	2.83	31.4	3.46	3.77	4.08	4.40	4.72	5.04
$-\frac{r_0}{x_0}(\theta-\theta_1)$ "	.56	.63	.69	.75	.81	.88	.94	1.01

CURRENT FOR θ_1 = ZERO

Cycle	9		10		11		12	
$\frac{E}{x}$	18390		18390		18390		18390	
θ	3060	3240	3420	3600	3780	3960	4140	4320
θ_1	0	0	0	0	0	0	0	0
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	1	1	1	1	1	1	1	1
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.01	.006	.0025	.0018	.001	.0009	.0005	.0004
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.345	.325	.305	.29	.27	.255	.24	.227
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	.01	.006	.0025	.0018	.001	.0009	.0005	.0004
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.345	$\mp$.325	$\pm$.305	$\mp$.29	$\pm$.27	$\mp$.255	$\pm$.24	$\mp$.227
Difference	+.355	-.319	+.307	-.288	+.271	-.2541	+.2405	-.2266
Diff.	+6530	-5860	+5640	-5300	+4980	-4670	+4420	-4170
$-\frac{r}{x}(\theta-\theta_1)$ Rad.	5.34	5.66	5.96	6.78	6.60	6.92	7.23	7.54
$-\frac{r_0}{x_0}(\theta-\theta_1)$ "	1.07	1.13	1.19	1.25	1.32	1.38	1.45	1.51

CURRENT FOR θ_1 = ZERO

Cycle	13		14		15		16	
$\frac{E}{x}$	18390		18390		18390		18390	
θ	4500	4680	4860	5040	5220	5400	5580	5760
θ_1	0	0	0	0	0	0	0	0
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	1	1	1	1	1	1	1	1
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.0004	.0003	.0002	.00013	.0001	.00006	.00005	.00004
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.205	.19	.18	.17	.16	.15	.14	.13
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	.0004	.0003	.0002	.00013	.0001	.00006	.00005	.00004
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.205	$\mp$.19	$\pm$.18	$\mp$.17	$\pm$.16	$\mp$.15	$\pm$.14	$\mp$.13
Difference	+.2054	-.1897	+.1802	-.1698	+.1601	-.15	+.14	-.13
Diff.	+ 3770	-3400	+3310	-3120	+2940	-2760	+2570	-2390
$-\frac{r}{x}(\theta-\theta_1)$ Rad.	7.854	8.168	8.482	8.796	9.110	9.424	9.738	10.052
$-\frac{r_0}{x_0}(\theta-\theta_1)$ "	1.572	1.635	1.697	1.650	1.822	1.884	1.947	2.010

CURRENT FOR θ_1 = ZERO

<u>Cycle</u>	17		18	
$\frac{E}{x}$	18390		18390	
θ	5940	6120	6300	6480
θ_1	0	0	0	0
Cos θ	-1	+1	-1	+1
Cos θ_1	1	1	1	1
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.000035			
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.123			
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	.000035			
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.123			
Difference	+.123			
Diff.	+2260	-2180		
$-\frac{r}{x}(\theta-\theta_1)$ Rad.	10.366	10.680	10.994	11.308
$-\frac{r_0}{x_0}(\theta-\theta_1)$ Rad.	2.072	2.135	2.197	2.260

POWER, θ_1 = ZERO

	Cycle	1		2		3		4	
1.	θ	90	270	450	630	810	990	1170	1350
2.	E	7350	7350	7350	7350	7350	7350	7350	7350
3.	$-\frac{r_o}{x_o}(\theta-\theta_1)$	.0314	.0942	.1570	.2198	.2826	.3454	.4082	.4710
4.	$\epsilon^{-\frac{r_o}{x_o}(\theta-\theta_1)}$	.97	.905	.855	.80	.76	.71	.67	.62
5.	Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
6.	$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
7.	$-\frac{r}{x}(\theta-\theta_1)$	.157	.47	.785	1.099	1.413	1.727	2.041	2.355
8.	$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.86	.62	.46	.335	.24	.17	.125	.095
9.	Cos θ_1	1	1	1	1	1	1	1	1
10.	2 x 4 x 5	+7130	-6650	+6280	-5880	+5580	-5220	+4920	-4560
11.	6 x 8 x 9	15.800	11.400	8.460	6.160	4.420	3.120	2.300	1.790
	10 x 11	112500	75800	53200	36200	24600	16300	11300	8160

POWER, θ_1 = ZERO

Cycle	5		6		7		8	
θ	1530	1710	1890	2070	2250	2430	2610	2790
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.5338	.5966	.6594	.7222	.7850	.8478	.9106	.9734
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.595	.55	.525	.485	.465	.43	.41	.38
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	2.669	2.983	3.297	3.611	3.925	4.239	4.553	4.867
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.07	.05	.036	.026	.0195	.0145	.0105	.0075
Cos θ_1	1	1	1	1	1	1	1	1
2 x 4 x 5	+4370	-4040	+3860	-3560	+3420	-3160	+3010	-2790
6 x 8 x 9	+1.290	+.920	+.662	+.478	+.358	+.266	+.193	+.138
10 x 11	+5640	- 3720	+2550	----Below permanent value ------				

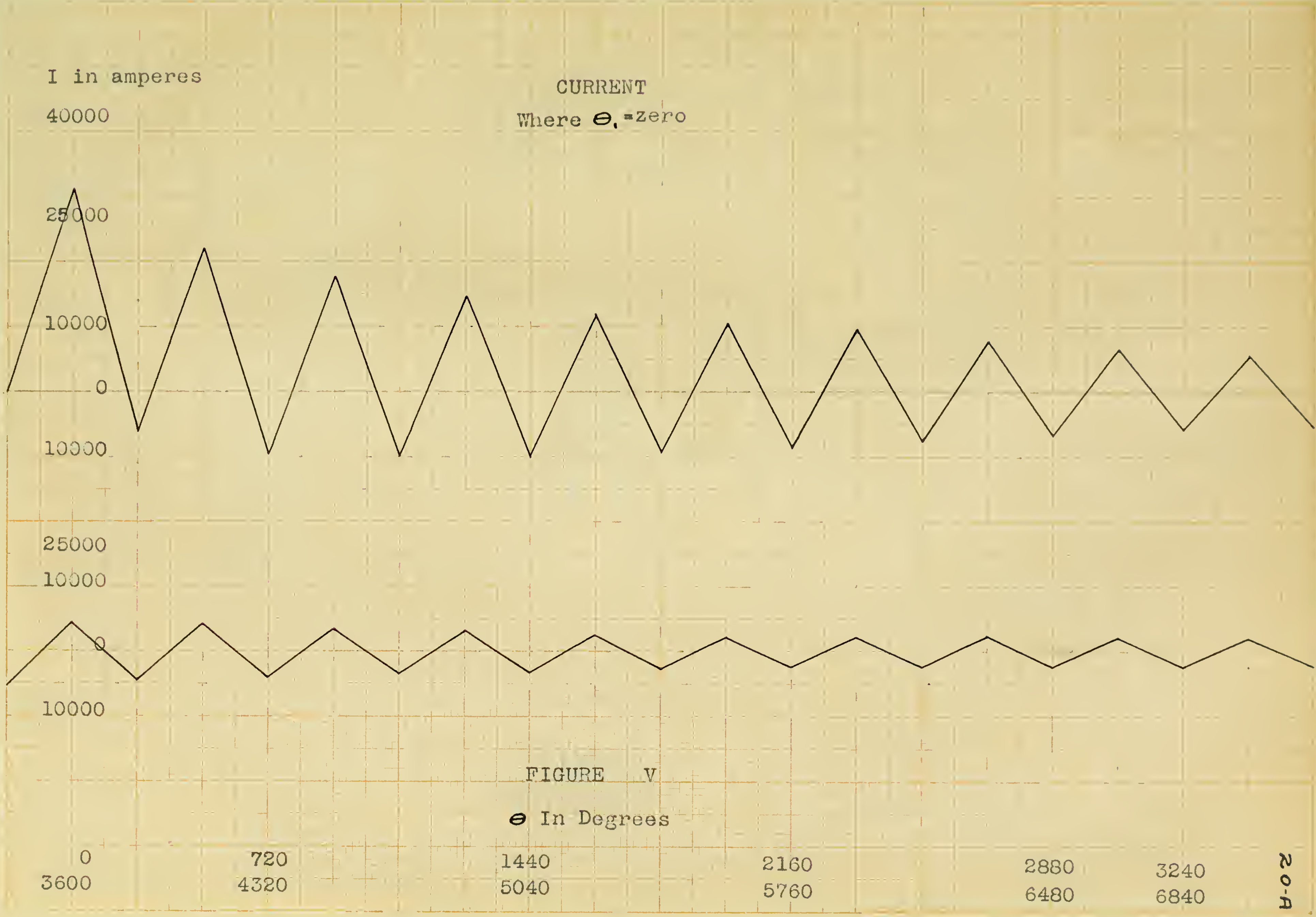

I in amperes
CURRENT
Where θ_1 =zero
40000
25000
10000
0
10000
25000
10000
0
10000
θ In Degrees
0
3600
720
4320
1440
5040
2160
5760
2880
6480
3240
6840

FIGURE V

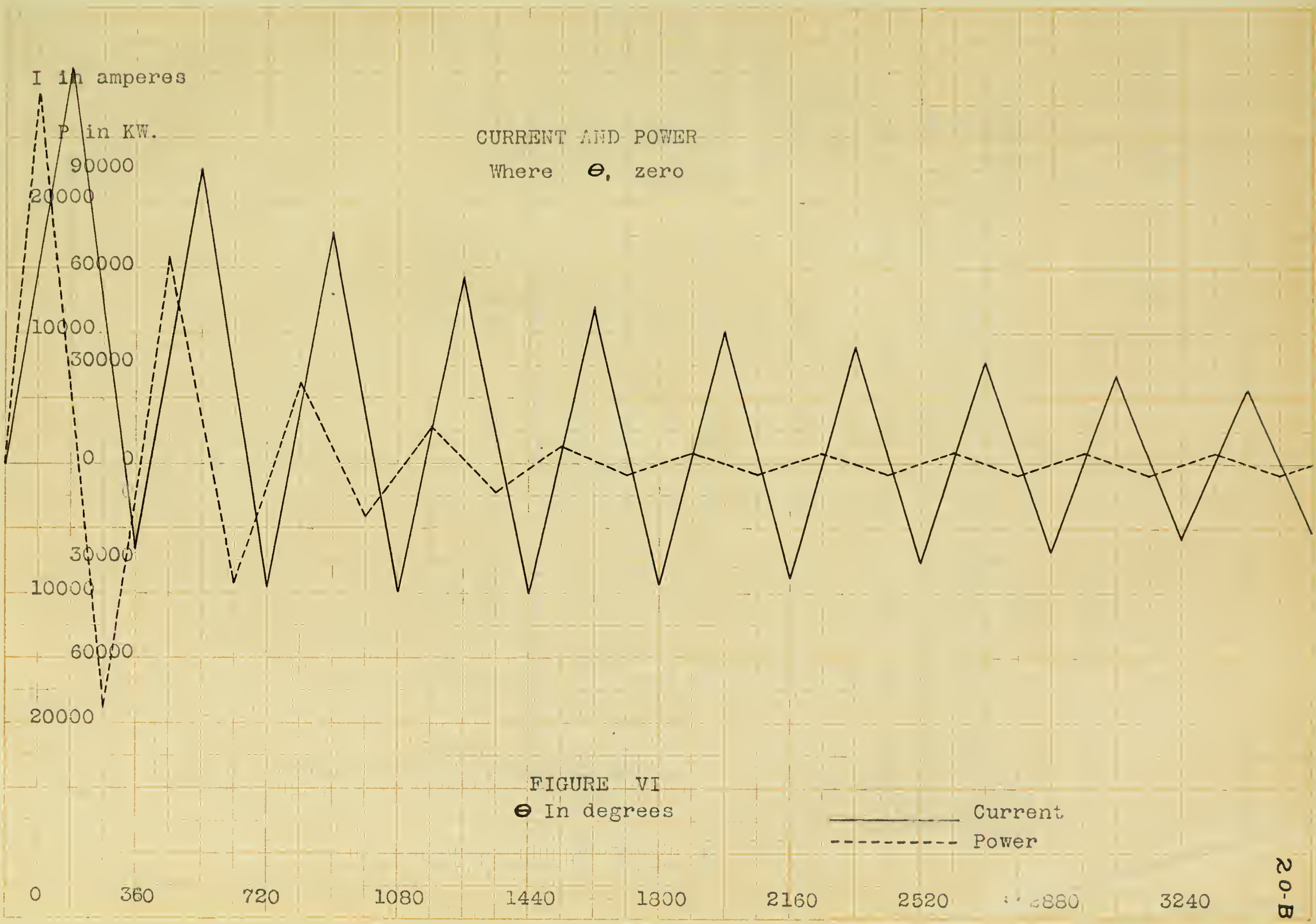


FIGURE VI
θ In degrees

CURRENT FOR $\theta_1 = 30^\circ$

Cycle	1		2		3		4	
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	180	360	540	720	900	1808	1260	1440
θ_1	30	30	30	30	30	30	30	30
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	.866	.866	.866	.866	.866	.866	.866	.866
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.78	.485	.425	.305	.225	.171	.115	.085
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.941	.885	.845	.825	.75	.71	.67	.626
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	.676	.421	.368	.264	.195	.148	.099	.0736
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.941	$\mp$.885	$\pm$.845	$\mp$.825	$\pm$.750	$\mp$.710	$\pm$.670	$\mp$.626
Difference	+1.617	-.464	+1.213	-.561	+.945	-.562	+.769	-.5524
Diff.	+29700	-8540	+22300	-10300	+17350	-10350	+14100	-10150
$-\frac{r}{x}(\theta-\theta_1)$ Rad.	.262	.576	.889	1.02	1.52	1.83	2.14	2.46
$-\frac{r_0}{x_0}(\theta-\theta_1)$ Rad.	.052	.113	.178	.24	.304	.366	.428	.492

CURRENT FOR θ_1 = 30°

Cycle	5		6		7		8	
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	1620	1800	1980	2160	2340	2520	2700	2880
θ_1	30	30	30	30	30	30	30	30
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	.866	.866	.866	.866	.866	.866	.866	.866
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.063	.045	.033	.030	.025	.02	.017	.068
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.595	.55	.518	.495	.465	.425	.41	.375
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$ cos θ_1	.0545	.039	.0286	.026	.0216	.0173	.0147	.059
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$ cos θ	-.595	+.55	-.58	+.495	-.465	+.425	-.410	+.375
Difference	+.6495	-.511	+.5466	-.469	+.4866	-.4077	+.4247	- .316
(Diff)	+11900	-9400	+10000	-8630	+ 8940	-7480	+7800	- 6800
$-\frac{r}{x}(\theta-\theta_1)$ rad.	2.78	3.09	3.4	3.72	4.03	4.35	4.66	4.97
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.556	.618	.68	.744	.806	.87	.932	.994

POWER, $\theta_1 = 30^o$

<u>Cycle</u>	1		2		3		4	
θ	90	270	450	630	810	990	1170	1350
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.0209	.0836	.1466	.209	.272	.334	.398	.460
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.97	.91	.86	.81	.77	.735	.69	.655
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	.104	.418	.733	1.045	1.36	1.67	1.99	2.3
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.90	.67	.5	.375	.265	.195	.14	.1
Cos θ_1	.866	.866	.866	.866	.866	.866	.866	.866
2 x 4 x 5	+7130	-6700	+6330	-5950	+5660	-5400	+5060	-4820
6 x 8 x 9	14.300	10.650	7.950	5.960	4.22	3.10	2.23	1.59
10 x 11	102000	71400	50200	35500	23850	16750	11300	7660

POWER, θ_1 = 30°

<u>Cycle</u>	5		6		7		8	
θ	1530	1710	1890	2070	2250	2430	2610	2790
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.524	.588	.650	.712	.774	.836	.90	.964
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.61	.58	.54	.505	.48	.45	.42	.395
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	2.62	2.94	3.25	3.56	3.87	4.18	4.5	4.82
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.07	.055	.04	.033	.020	.015	.010	.008
Cos θ_1	.866	.866	.866	.866	.866	.866	.866	.866
2 x 4 x 5	+4480	-4260	+3970	-3710	+3530	-3310	+3090	-2900
6 x 8 x 9	1.11	.875	.636	.525	.318	.238	.159	.127
10 x 11	+4980	-3730	+2520	-1945	+1120	-788	+492	-369

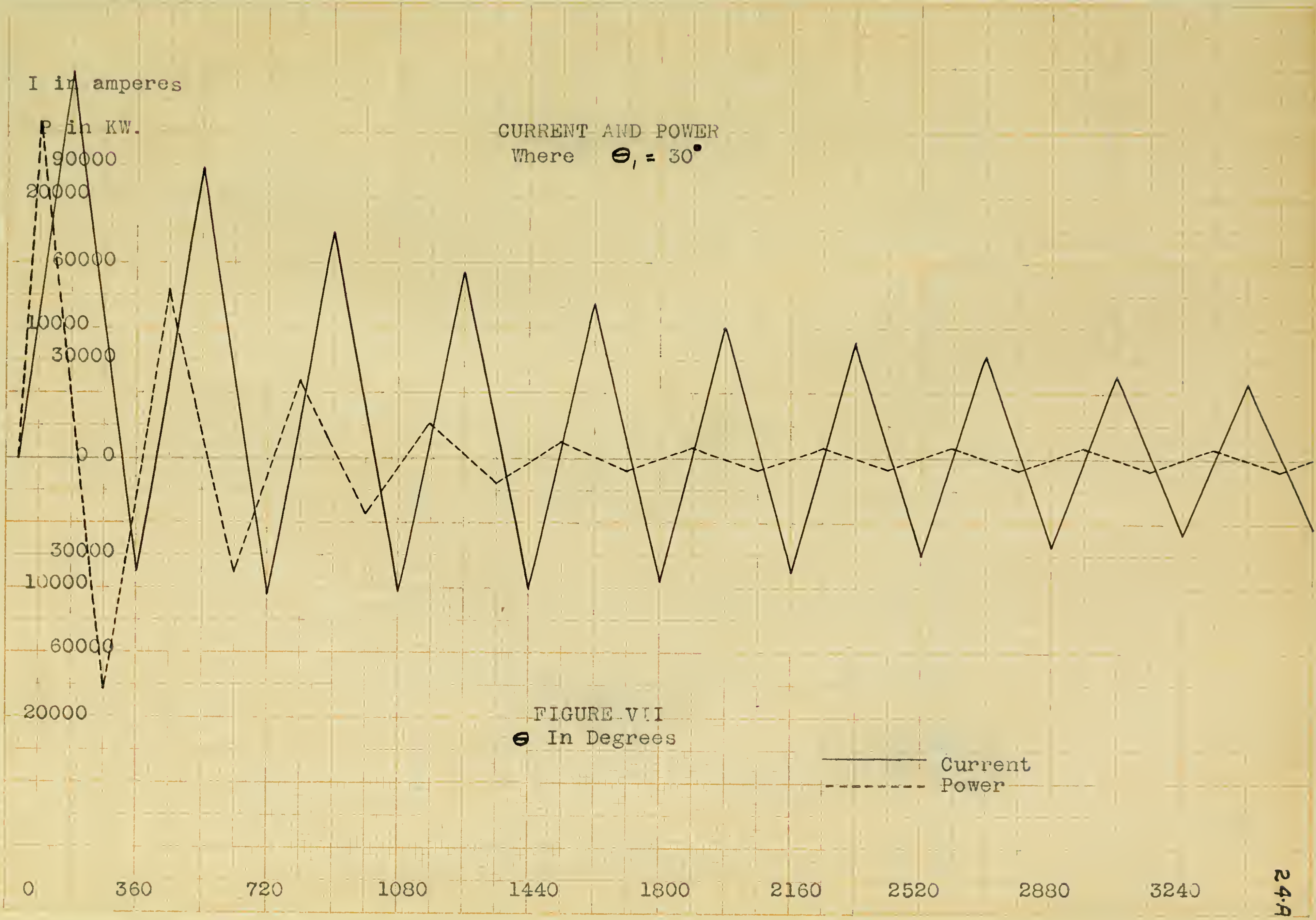


FIGURE VII

θ In Degrees

CURRENT FOR $\theta_1 = 60^0$

Cycle	1		2		3		4	
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	180	360	540	720	900	1080	1260	1440
θ_1	60	60	60	60	60	60	60	60
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	.5	.5	.5	.5	.5	.5	.5	.5
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.825	.61	.45	.32	.24	.185	.125	.09
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.95	.865	.845	.805	.77	.715	.67	.64
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	.412	.305	.225	.16	.12	.092	.062	.045
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm.95$	$\mp.865$	$\pm.845$	$\mp.805$	$\pm.77$	$\mp.715$	$\pm.67$	$\mp.64$
Difference	+1.362	-.560	+1.070	-.645	+.89	-.623	+.732	-.595
Diff.	+25000	-10300	+19670	-11850	+16350	-11450	+13450	-10900
$-\frac{r}{x}(\theta-\theta_1)$ rad.	.209	.523	.838	1.15	1.46	1.78	2.09	2.41
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.0418	.1046	.1676	.230	.292	.356	.418	.482

CURRENT FOR θ_1 = 60°

Cycle	5		6		7		8	
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	1620	1800	1980	2160	2340	2520	2700	2880
θ_1	60	60	60	60	60	60	60	60
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	.5	.5	.5	.5	.5	.5	.5	.5
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.065	.045	.035	.03	.025	.02	.017	.015
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.595	.565	.525	.50	.465	.44	.41	.385
cos θ_1	.032	.022	.017	.015	.012	.010	.008	.007
cos θ	$\pm$.595	$\mp$.565	$\pm$.525	$\mp$.50	$\pm$.465	$\mp$.44	$\pm$.41	$\mp$.385
Difference	+.627	-.543	+.542	-.415	+.477	-.43	+.418	-.378
(Diff)	+11500	-10000	+9960	-8920	+8750	-790	+770	-6950
$-\frac{r}{x}(\theta-\theta_1)$ rad.	2.72	3.04	3.35	3.67	3.98	4.28	4.60	4.92
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.544	.608	.670	.784	.796	.856	.920	.984

POWER, $\theta_1 = 60^0$

Cycle	1		2		3		4	
θ	90	270	450	630	810	990	1170	1350
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.0104	.0736	.1361	.1975	.2615	.3235	.3875	.4495
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.975	.925	.875	.825	.78	.74	.705	.66
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	.052	.366	.681	.993	1.308	1.618	1.938	2.248
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.945	.71	.53	.38	.275	.205	.15	.105
Cos θ_1	.5	.5	.5	.5	.5	.5	.5	.5
2 x 4 x 5	+7160	-6800	+6430	-6050	+5730	-5440	+5180	-4850
6 x 8 x 9	8.670	6.52	4.87	3.49	2.53	1.88	1.38	.965
10 x 11	+62000	-44300	+31300	-21100	+14500	-10200	+7150	-4675

POWER, $\theta_1 = 60°$

Cycle	5		6		7		8	
θ	1530	1710	1890	2070	2250	2430	2610	2790
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_o}{x_o}(\theta-\theta_1)$	.5135	.5775	.6495	.7015	.7635	.8255	.8895	.9535
$\epsilon^{-\frac{r_o}{x_o}(\theta-\theta_1)}$	.615	.584	.54	.515	.485	.455	.425	.395
Sine θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	2.568	2.888	3.198	3.508	3.818	4.128	4.448	4.768
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.075	.055	.041	.034	.022	.016	.011	.0085
Cos θ_1	.5	.5	.5	.5	.5	.5	.5	.5
2 x 4 x 5	+4520	-4280	+3960	-3780	+3560	-3340	+3120	-2900
6 x 8 x 9	.688	.505	.377	.312	.202	.147	.101	.078
10 x 11	+3100	-2160	+1490	-1180	+720	-492	+313	-226

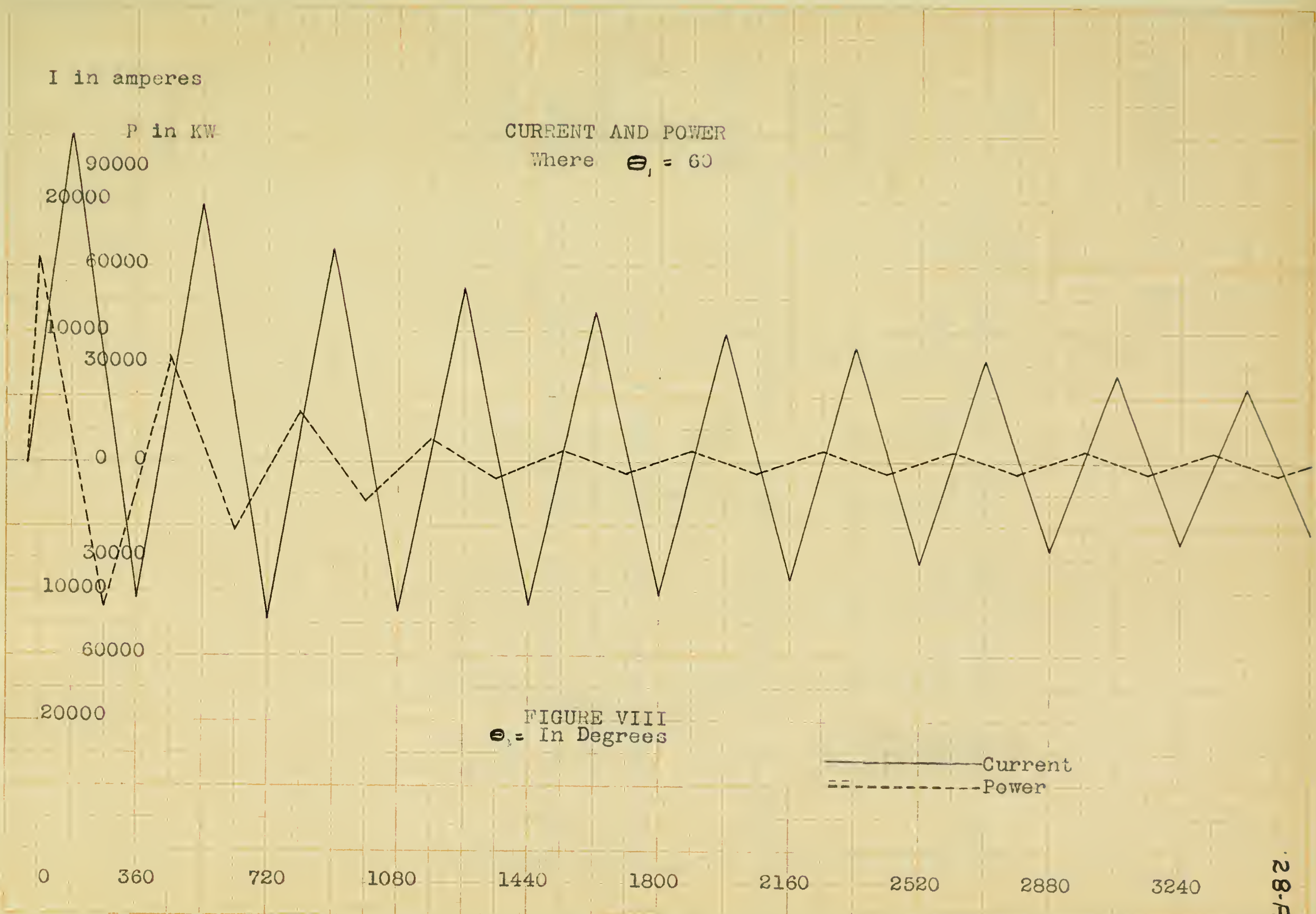


FIGURE VIII
θ_1 = In Degrees

CURRENT FOR θ_1 = 90^0

Cycle	1		2		3		4	
$\frac{E}{X}$	18380	18380	18380	18380	18380	18380	18380	18380
θ	180	360	540	720	900	1080	1260	1440
θ_1	90	90	90	90	90	90	90	90
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	0	0	0	0	0	0	0	0
	(Makes no difference, since multiplied by zero gives zero)							
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.97	.905	.865	.81	.77	.715	.685	.64
cos	0	0	0	0	0	0	0	0
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$ cos θ	$\pm$.97	$\mp$.905	$\pm$.865	$\mp$.81	$\pm$.77	$\mp$.715	$\pm$.685	$\mp$.64
Difference	$\pm$.97	$\mp$.905	$\pm$.865	$\mp$.81	$\pm$.77	-.715	+.685	-.64
Diff.	+17800	-16600	+15900	-14850	+14100	-13100	+12600	-11750
$-\frac{r}{x}(\theta-\theta_1)$ rad.	.157	.46	.785	1.1	1.41	1.73	2.04	2.36
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.0314	.092	.157	.22	.282	.346	.408	.472

CURRENT FOR $\theta_1 = 90^\circ$

<u>Cycle</u>	5		6		7		8	
$\frac{E}{X}$	18380	18380	18380	18380	18380	18380	18380	18380
θ	1620	1800	1980	2160	2340	2520	2700	2880
θ_1	90	90	90	90	90	90	90	90
Cos θ	-1	+1	-1	+1	-1	+1	- 1	+1
Cos θ_1	0	0	0	0	0	0	0	0
(Makes no difference since multiplied by zero gives zero)								
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.61	.565	.54	.5	.475	.44	.42	.385
cos	0	0	0	0	0	0	0	0
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.61	$\mp$.565	$\pm$.54	$\mp$.5	$\pm$.475	$\mp$.44	$\pm$.42	$\mp$.385
Difference	+.61	-.565	+.54	-.5	$\pm$.475	$\mp$.44	$\pm$.42	$\mp$.385
Diff.	+11200	-10400	+9920	-9195	$\pm$8730	$\mp$8090	$\pm$7720	$\mp$7070
$-\frac{r}{x}(\theta-\theta_1)$ rad.	2.68	2.98	3.3	3.61	3.93	4.24	4.55	4.86
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.536	.596	.66	.722	.786	.848	.910	.992

POWER $\theta_1 = 90^0$

Cycle	1		2		3		4	
θ	135	315	495	675	855	1035	1215	1395
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.0157	.0786	.1414	.2042	.2670	3298	.3926	.4554
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.985	.93	.86	.815	.76	.72	.685	.635
Sin θ	+.707	-.707	+.707	-.707	+.707	-.707	+.707	-.707
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.0157	.0786	.1414	.2042	.2670	.3298	.3926	.4554
$-\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.985	.93	.86	.815	.76	.72	.685	.635
Cos θ	-.707	+.707	-.707	+.707	-.707	+.707	-.707	+.707
2 x 4 x 5	+5120	-4840	+4470	-4240	+3950	-3740	+3560	-3300
6 x 8 x 9	-12.800	+12.100	-11.200	+10.600	-9.870	+9.360	-8.900	+8.250
10 x 11	-65500	-58500	-50000	-45000	-38900	-35000	-31700	-27200

POWER, $\theta_1 = 90^\theta$

Cycle	5		6		7		8	
θ	1573	1755	1935	2115	2295	2475	2655	2835
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.5182	.5810	.6438	.7066	.7694	.8322	.8950	.9578
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.59	.565	.525	.50	.465	.44	.42	.385
Sin θ	+.707	-.707	+.707	-.707	+.707	-.707	+.707	-.707
$\frac{E}{X}$	18380	18390	18390	18390	18390	18390	18390	18390
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.5182	.5810	.6438	.7066	.7694	.8322	.8950	.9578
$-\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.59	.565	.525	.50	.465	.44	.42	.385
Cos θ	-.707	+.707	-.707	+.707	- .707	+.707	-.707	+.707
2 x 4 x 5	+3060	-2940	+2730	-2600	+2420	-2285	+2180	-2000
6 x 8 x 9	-7.660	+7.350	-6.820	+6.500	-6.050	+5.720	-5.45	+5.030
10 x 11	-23500	-21600	-18600	-16900	-14600	-13100	-11830	-10060

POWER, $\theta_1 = 90^{0}$

Cycle	1		2		3		4	
θ	45	225	405	585	765	945	1125	1305
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	+.0157	-.047	+.1098	-.1726	+.2354	-.2982	+.3610	-.4238
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	1.17	.955	.895	.835	.79	.74	.705	.65
Sin θ	+.707	-.707	+.707	-.707	+.707	-.707	+.707	-.707
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r_0}{x_0}(\theta-\theta_1)$	+.0157	-.047	-.1098	-.1726	-.2354	-.2982	-.3610	-.4238
$-\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	-1.17	-.955	-.895	-.835	-.79	-.74	-.705	-.65
Cos θ	+.707	-.707	+.707	-.707	+.707	-.707	+.707	-.707
2 x 4 x 5	+6080	-4960	+ 4650	-4340	+4110	-3850	+3670	-3380
6 x 8 x 9	+15.200	-12.400	+11.650	-10.850	+10.250	-9.610	+9.150	-8.450
10 x 11	+92500	+61500	+54300	+47200	+42200	+37000	+33600	+28600

POWER, $\theta_1 = 90^0$

Cycle	5		6		7		8	
θ	1485	1665	1845	2025	2205	2385	2565	2745
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.4866	.5494	.6122	.6750	.7388	.8016	.8644	.9272
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.615	.58	.545	.51	.48	.45	.42	.398
Sin θ	.707	.707	.707	.707	.707	.707	.707	.707
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r_0}{x_0}(\theta-\theta_1)$	-.4866	-.5494	-.6122	-.6750	-.7388	-.8016	-.8644	-.9272
$-\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	-.615	-.58	-.545	-.51	-.48	-.45	-.42	-.348
Cos θ	+.707	-.707	+.707	-.707	+.707	-.707	+.707	-.707
2 x 4 x 5	+3200	-3020	+2830	-2650	+2495	-2340	+2180	-2070
6 x 8 x 9	+8.000	-7.540	+7.100	-6.630	+6.240	-5.850	+5.460	-5.175
10 x 11	+25600	+22800	+20200	+17550	+15500	+13675	+11900	+10700

POWER, $\theta_1 = 90^{\circ}$

Cycle	1		2		3		4	
θ	90	270	450	630	810	990	1170	1350
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	0	.0628	.1256	.1880	.2510	.4140	.3770	.4390
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	1	.94	.875	.83	.79	.745	.675	.645
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r_0}{x_0}(\theta-\theta_1)$	0	.314	.629	.941	1.256	1.556	1.886	2.196
$-\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	1	.72	.535	.39	.285	.21	.14	.11
Cos θ	0	0	0	0	0	0	0	0
2 x 4 x 5	+7350	-6900	+6430	-6100	+5800	-5470	+4960	-4730
6 x 7 x 8	Power is zero.							
10 x 11	Power is zero.							

POWER, θ_1 = 90^0

Cycle	5		6		7		8	
θ	1530	1710	1890	2070	2250	2430	2610	2790
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.5030	.5670	.6390	.6910	.7530	.8150	.8790	.9430
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.6	.565	.53	.51	.475	.44	.42	.39
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r_0}{x_0}(\theta-\theta_1)$	2.516	2.836	3.146	3.456	3.766	4.076	4.396	4.716
$-\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.08	.06	.0415	.03	.023	.016	.012	.008
Cos θ	0	0	0	0	0	0	0	0
2 z 4 x 5	4410	4150	3890	3750	0	0	0	0

6 x 8 x 9 Power is zero for these values

10 x 11 of θ . Also for angles (θ + 90),

where θ = angles given above.

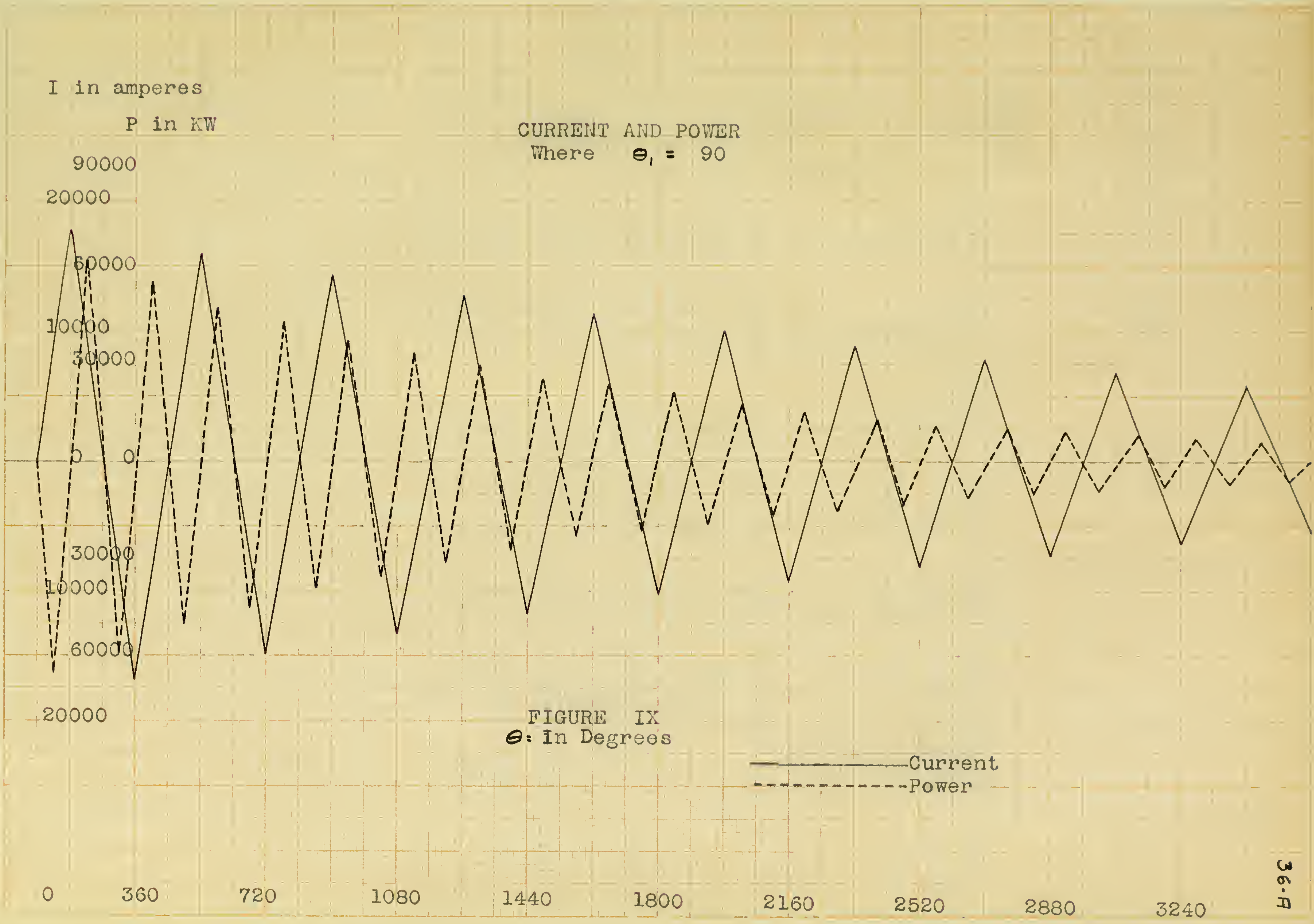


FIGURE IX
θ: In Degrees

CURRENT FOR $\theta_1 = 120^\circ$

Cycle	1		2		3		4	
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	180	360	540	720	900	1080	1260	1440
θ_1	120	120	120	120	120	120	120	120
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	-.5	-.5	-.5	-.5	-.5	-.5	-.5	-.5
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.90	.675	.5	.37	.265	.195	.14	.10
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.965	.91	.86	.82	.77	.735	.69	.65
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	-.45	-.337	-.25	-.185	-.132	-.097	-.07	-.05
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.965	$\mp$.91	$\pm$.86	$\mp$.82	$\pm$.77	$\mp$.735	$\pm$.69	$\mp$.65
Difference	+.515	-1.247	+.61	-1.005	+.638	-.832	+.62	-.70
Diff.	+9460	-22950	+11200	-18500	+11720	-15295	+11400	-12850
$-\frac{r}{x}(\theta-\theta_1)$ rad.	.104	.418	.732	1.04	1.36	1.67	1.99	2.3
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.021	.0837	.146	.21	.272	.335	.398	.46

CURRENT FOR θ_1 = 120°

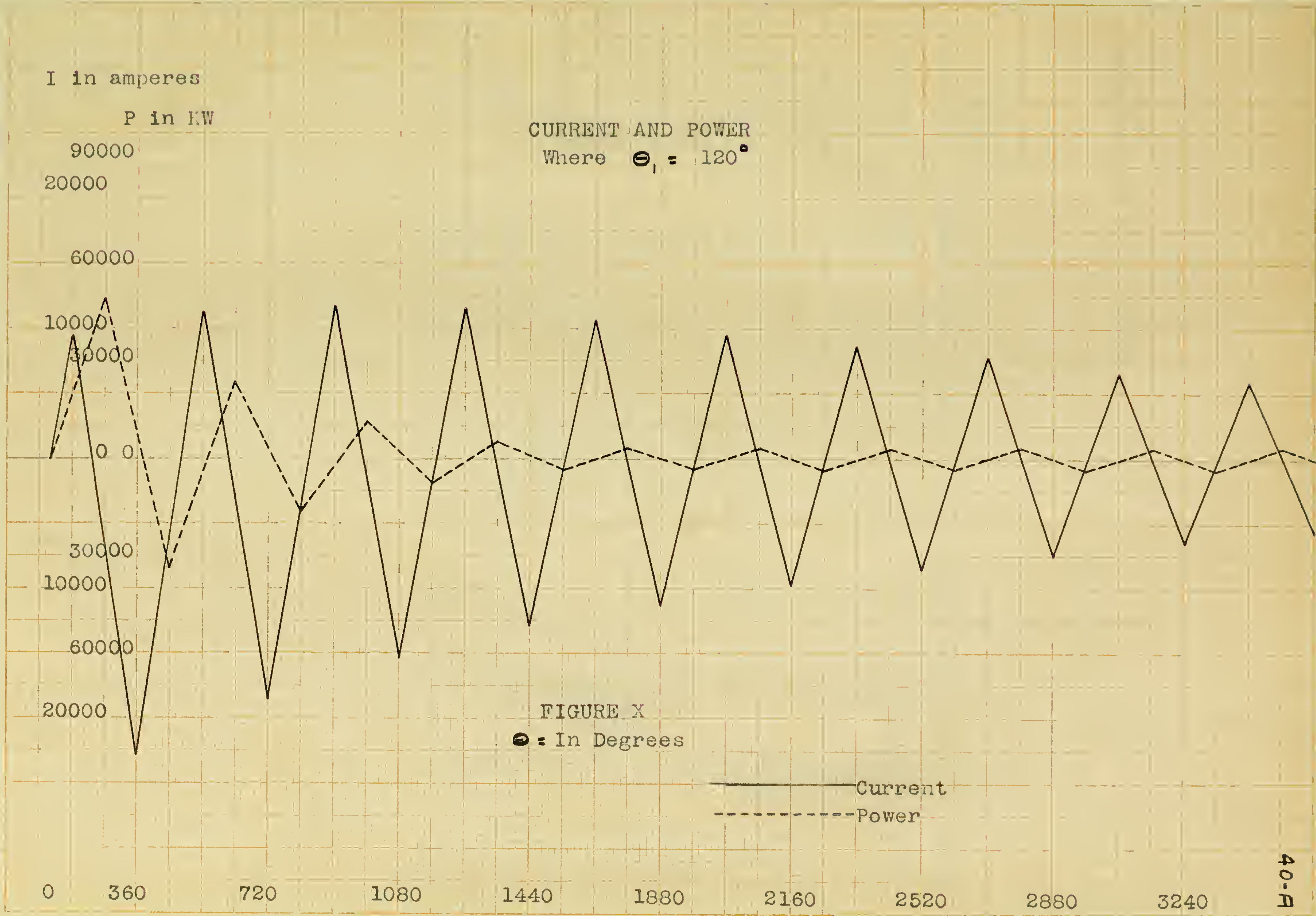
Cycle	5		6		7		8	
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	1620	1800	1980	2160	2340	2520	2700	2880
θ_1	120	120	120	120	130	120	120	120
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	-.5	-.5	-.5	-.5	-.5	-.5	-.5	-.5
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.07	.053	.05	.03	.025	.024	.019	.015
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.61	.58	.54	.51	.48	.45	.42	.395
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$cos θ_1	-.035	-.026	-.025	-.015	-.0125	-.012	-.0095	-.0075
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$cos θ	±.61	∓.58	±.54	∓.51	±.48	∓.45	±.42	∓.395
Difference	+.575	-.606	+.515	-.525	+.4675	-.462	+.4105	-.4025
Diff.	+10550	-11150	+9470	-9650	+8600	-8490	+9550	-7400
$-\frac{r}{x}(\theta-\theta_1)$rad.	2.62	2.93	3.24	3.56	3.87	4.18	4.5	4.81
$-\frac{r_0}{x_0}(\theta-\theta_1)$rad.	.523	.586	.65	.712	.775	.837	.9	.961

POWER $\theta_1 = 120^{\circ}$

Cycle	1		2		3		4	
θ	90	270	450	630	810	990	1170	1350
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_o}{x_o}(\theta-\theta_1)$	.0104	.0523	.1151	.1775	.2405	.3025	.3665	.4285
$\epsilon^{-\frac{r_o}{x_o}(\theta-\theta_1)}$	1.01	.945	.89	.835	.785	.735	.695	.65
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	.052	.262	.576	.890	1.204	1.518	1.832	2.146
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	1.05	.77	.565	.42	.3	.215	.156	.115
Cos θ_1	-.5	-.5	-.5	-.5	-.5	-.5	-.5	-.5
2 x 4 x 5	+7430	-6950	+6550	-6140	+5760	-5400	+5100	-4770
6 x 8 x 9	-9.65	-7.070	-5.180	-3.860	-2.760	-1.975	-1.430	-1.055
10 x 11	-71600	+49200	-33900	+23700	-15900	+10680	-7300	+5030

POWER, $\theta_1 = 120^0$

Cycle	5		6		7		8	
θ	1530	1710	1890	2070	2250	2430	2610	2790
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.4925	.5565	.6285	.6805	.7425	.8145	.8685	.9325
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.61	.575	.535	.51	.48	.45	.42	.405
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{x}$	13890	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	2.460	2.774	3.088	3.402	3.716	4.030	4.344	4.65
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.07	.065	.044	.032	.0235	.017	.012	.0095
Cos. θ_1	-.5	-.5	-.5	-.5	-.5	-.5	-.5	-.5
2 x 4 x 5	+4480	-4230	+3930	-3750	+3530	-3310	+3080	-2980
6 x 8 x 9	-.643	-.596	-.405	-.294	-.216	-.156	-.110	-.874
10 x 11	-2880	+2520	-1590	+1100	-763	+517	-339	+260



CURRENT AND POWER
Where $\Theta_1 = 120°$

FIGURE X
Θ = In Degrees

CURRENT FOR θ_1 = 150°

Cycle	1		2		3		4	
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	180	360	540	720	900	1080	1260	1440
θ_1	150	150	150	150	150	150	150	150
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	.866	.866	.866	.866	.866	.866	.866	.866
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.95	.72	.53	.375	.275	.205	.15	.105
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.98	.92	.875	.82	.78	.735	.70	.655
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	-.822	-.623	-.458	-.324	-.238	-.177	-.13	-.091
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	$\pm$.98	$\mp$.92	$\pm$.875	$\mp$.82	$\pm$.78	$\mp$.735	$\pm$.70	$\mp$.655
Difference	+.158	-1.543	+.417	-1.144	+.542	-.912	+.57	-.746
Diff.	+2900	-28300	+7660	-21000	+9950	-16750	+10450	-13700
$-\frac{r}{x}(\theta-\theta_1)$ rad.	.052	.366	.68	.995	1.31	1.62	1.93	2.25
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.011	.0732	.136	.20	.262	.325	.383	.45

CURRENT FOR θ_1 = 150°

Cycle	5		6		7		8	
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
θ	1620	1800	1980	2160	2340	2520	2700	2880
θ_1	150	150	150	150	150	150	150	150
Cos θ	-1	+1	-1	+1	-1	+1	-1	+1
Cos θ_1	-.866	-.866	-.866	-.866	-.866	-.866	-.866	-.866
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.075	.055	.04	.035	.025	.023	.019	.015
$\epsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.615	.58	.535	.515	.485	.455	.425	.395
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}\cos\theta_1$	-.065	-.047	-.034	-.030	-.0216	-.0199	-.0165	-.013
$\epsilon^{\frac{r_0}{x_0}(\theta-\theta_1)}\cos\theta$	±.615	∓.58	±.535	∓.515	±.485	∓.455	±.425	∓.395
Difference	+.550	-.627	+.501	-.545	+.4634	-.4749	+.4085	-.408
Diff.	+10100	-11500	+9200	-10000	+8500	-8720	+7500	-7500
$-\frac{r}{x}(\theta-\theta_1)$ rad.	2.57	2.87	3.19	3.51	3.81	4.13	4.45	4.75
$-\frac{r_0}{x_0}(\theta-\theta_1)$ rad.	.513	.576	.64	.702	.765	.827	.89	.951

POWER, $\theta_1 = 150^\circ$

Cycle	1		2		3		4	
θ	90	270	450	630	810	990	1170	1350
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_o}{x_o}(\theta-\theta_1)$	+.0208	-.0418	.1046	.1674	.2302	.2930	.3558	.4186
$\epsilon^{-\frac{r_o}{x_o}(\theta-\theta_1)}$	1.02	.95	.90	.85	.795	.75	.70	.655
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{x}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	+.104	.210	.524	.848	1.152	1.466	1.780	2.094
$\epsilon^{-\frac{r}{x}(\theta-\theta_1)}$	1.11	.81	.595	.44	.315	.235	.165	.12
Cos θ_1	-.866	-.866	-.866	-.866	-.866	-.866	-.866	-.866
2 x 4 x 5	+7500	-6980	+6620	-6250	+5850	-5520	+5150	-4820
6 x 8 x 9	-17.69	-12.900	-9.460	-7.	-5.02	-3.74	-2.62	-1.91
10 x 11	-132500	+90000	-62600	+43700	-29300	+20600	-13500	+9200

POWER, $\theta_1 = 150^0$

Cycle	5		6		7		8	
θ	1530	1710	1890	2070	2250	2430	2610	1790
E	7350	7350	7350	7350	7350	7350	7350	7350
$-\frac{r_0}{x_0}(\theta-\theta_1)$	.4814	.5442	.6070	.6698	.7326	.7954	.8582	.9210
$\varepsilon^{-\frac{r_0}{x_0}(\theta-\theta_1)}$	.62	.58	.55	.505	.485	.45	.41	.395
Sin θ	+1	-1	+1	-1	+1	-1	+1	-1
$\frac{E}{X}$	18390	18390	18390	18390	18390	18390	18390	18390
$-\frac{r}{x}(\theta-\theta_1)$	2.408	2.722	3.036	3.350	3.664	3.978	4.292	4.606
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$	.09	.065	.048	.034	.0245	.0185	.0135	.01
Cos. θ_1	-.866	-.866	-.866	-.866	-.866	-.866	-.866	-.866
2 x 4 x 5	+4550	-4260	+4040	-3710	+3560	-3310	+3010	-2900
6 x 8 x 9	-1.43	-1.03	-.764	-.541	-.39	-.294	-.215	-.159
10 x 11	-6500	+4400	-3080	+2101	-1390	+974	-647	+462

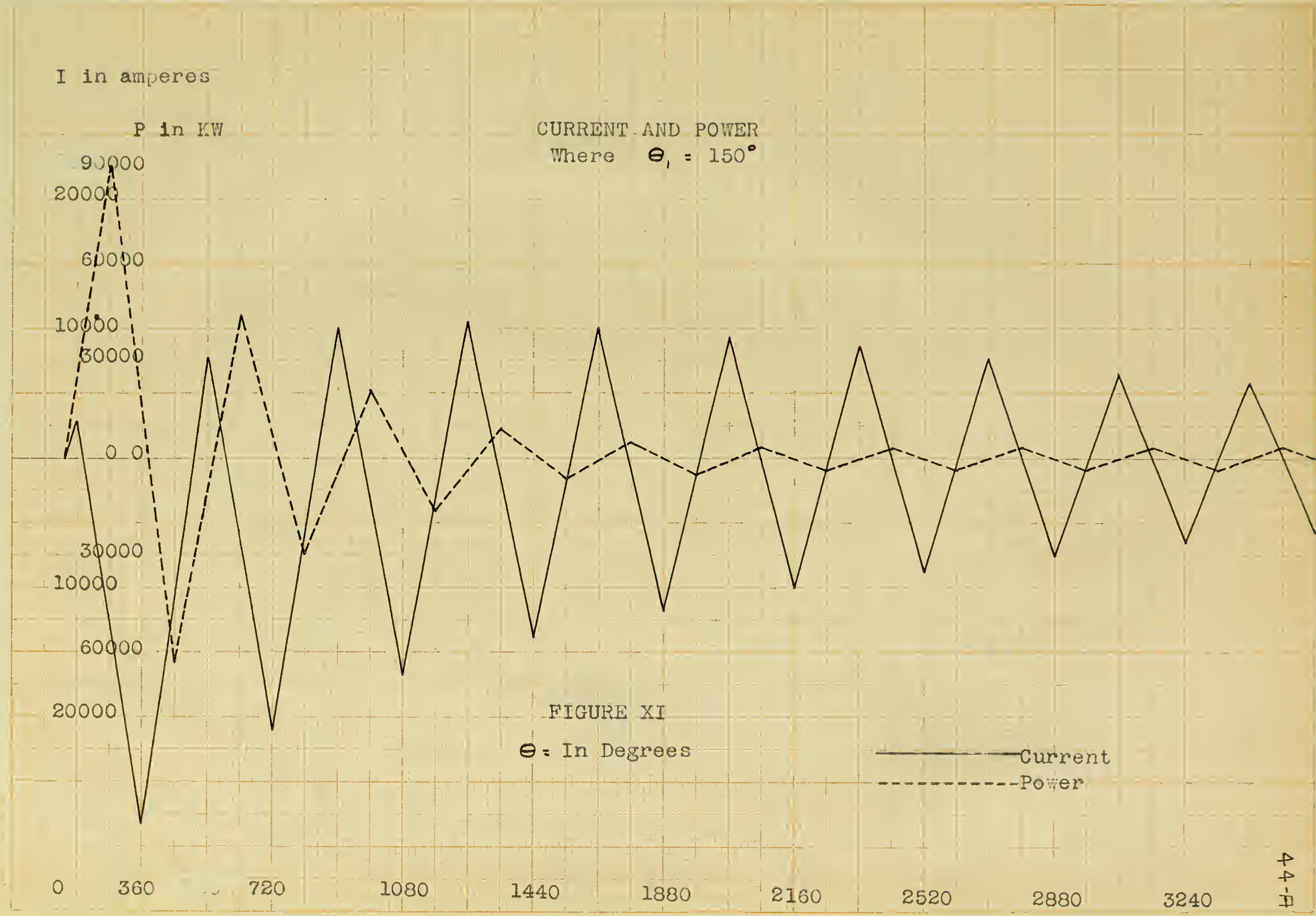

I in amperes
P in KW
CURRENT AND POWER
Where $\theta_1 = 150°$
90000
20000
60000
10000
30000
0 0
30000
10000
60000
20000
0
360
720
1080
1440
1880
2160
2520
2880
3240
θ = In Degrees
Current
Power

FIGURE XI

IV. CONCLUSION.

From this we see that the differences between the positive maximum and negative maximum of current, for corresponding cycles are equal, but the numerical maximum occurs in a positive direction when the angle θ_1 is zero, and in a negative direction when θ_1 is 180°. When θ_1 is 90° the positive maximum is equal to the negative maximum, and is practically equal to one half the positive maximum when θ_1 equals zero. During every 180° the curves repeat themselves in the opposite direction.

For power the results are somewhat different. For all values of θ_1 the power is first in a positive direction with the exception where $\theta_1 = 90°$. In this case we have double frequency and the resulting effective power per phase is nil. The power curves repeat themselves every 180° in the same direction.

It is also seen here that the maximum values of power occur 90° behind the maximum values of current.

For this particular alternator the maximum value of current was fifteen times the value of normal current, and, in general, the value lies between ten and twenty times normal value of current for turbo generators of this size.

The power at its maximum value for this generator was twenty-five times the normal value of power, which may be expected for any turbo generator of this size.